

油茶象幼虫虫龄的划分

李志文, 何立红, 夏 姣, 马 玲, 曾爱平*

(湖南农业大学昆虫研究所, 植物病虫害生物学与防控湖南省重点实验室, 长沙 410128)

摘要:【目的】油茶象 *Curculio chinensis* Chevrolat 是我国特有木本油料树种——油茶 *Camellia meiocarpa* 的专性蛀果害虫,常导致大量落果。幼虫准确分龄是其生物学、生态学及防控研究的基础,但对钻蛀性昆虫来说,这非常困难。本研究旨在明确研究样地油茶象幼虫龄数及各龄形态指标极差,试图探讨确定钻蛀性昆虫龄数及合理划分虫龄的可靠方法。【方法】收集了 1 253 头不同发育阶段的幼虫,测量头壳宽、头壳长和上颚宽 3 个形态指标,用多峰拟合分析频次分布资料,结合戴氏法则判断幼虫龄数。以正态曲线交点作为相邻虫龄分界点,计算各龄幼虫测量指标的平均值、极差、增长率及误判率。【结果】头壳宽、头壳长和上颚宽频次分布多峰拟合均呈显著的 5 个正态峰($P < 0.01$),对应 5 个虫龄;头壳宽、头壳长和上颚宽 3 个形态指标均以对 3 龄幼虫的误判率最大,分别为 6.04%, 7.03% 和 6.51%,而对其他虫龄误判率均小于 5%,提示 3 个形态指标均可作为油茶象虫龄划分的可靠依据,以头壳宽最佳。各龄幼虫头壳宽、头壳长及上颚宽增长率依次为 1.41~1.54, 1.43~1.61 及 1.44~1.64,基本恒定,其平均值的自然对数与虫龄均呈极显著线性正相关($P < 0.01$),油茶象幼虫头壳生长呈间断性几何级数增长,符合戴氏法则。【结论】油茶象幼虫具 5 个虫龄,不同于前人报道的仅 4 个虫龄;多峰拟合可用于确定钻蛀性昆虫或野外种群的龄数,特别是为相邻虫龄形态指标重叠区虫龄划分提供有效方法。

关键词: 油茶象; 头壳宽; 头壳长; 上颚宽; 频次分布; 多峰拟合; 戴氏法则

中图分类号: Q968 文献标识码: A 文章编号: 0454-6296(2015)02-0181-09

Determination of larval instars of the camellia weevil, *Curculio chinensis* (Coleoptera: Curculionidae)

LI Zhi-Wen, HE Li-Hong, XIA Jiao, MA Ling, ZENG Ai-Ping* (Institute of Insect, Hunan Agricultural University/ Hunan Provincial Key Laboratory for Biology and Control of Plant Diseases and Insect Pests, Changsha 410128, China)

Abstract: 【Aim】The camellia weevil, *Curculio chinensis* Chevrolat, is an important pest of the fruits of oil tea camellia (*Camellia* spp.) in China. Its infestation often leads to a lot of fruit drop from the camellia plants. For the study of the biology and ecology of weevil, it is very important to be able to determine the instar of the larva. However, in the case of xylophagous insects, this is particularly difficult. This study aims to clarify the number of larval instars of this pest, to identify the ranges of the instars in our study area and to design a reliable method for determining the instars of an individual larva.

【Methods】In 2014, 1 253 larvae of *C. chinensis* were collected from *Camellia meiocarpa*, and the head capsule width and length, and the mandible width of each larva were measured. Frequency distribution of the data was fitted using multiple peak fit (in Origin 9.0), the separation points of adjacent instars were determined by the intersection points of the normal curve, and then the means, range, growth ratio, and misclassification probability for all larval instars of the weevil were calculated. For the determination of the instar number, the Dyar's rule was also used. 【Results】Multiple peak fit of the frequency distribution of the head capsule data resulted in 5 normal and distinct peaks ($P < 0.01$), representing the five instars (1st–5th instars). The misclassification probability of the 3rd instar larva was 6.04%, 7.03% and 6.51% for the head capsule width, head capsule length and mandible width, respectively. The misclassification probability of the other instars was less than 5%, suggesting that the 3 morphological measurements could be used to identify the weevil's larval instars, of which the head

基金项目: 湖南省现代农业产业技术体系(湘农业联[2012]278号); 湖南省科技厅项目(2010NK3011, 2011FJ4298)

作者简介: 李志文, 男, 1976年8月生, 湖南衡阳人, 硕士, 主要从事昆虫生态、害虫防治等方面的研究, E-mail: lizhw809718@aliyun.com

* 通讯作者 Corresponding author, E-mail: apzengchina@163.com

收稿日期 Received: 2014-10-27; 接受日期 Accepted: 2015-01-08

capsule width is the most important one. The growth ratios of the instars were almost constant, being 1.41 – 1.54, 1.43 – 1.61 and 1.44 – 1.64 for head capsule width, head capsule length and mandible width, respectively. The positive correlation between the natural logarithm of the measurements and the larval instars showed that the larval growth of the weevil followed Dyar's rule of a geometrical growth pattern. 【Conclusion】 The camellia weevil has 5 instars instead of the 4 instars found in the previous research. Multiple peak fit is useful to determine the instar number of xylophagous insects or field collected larvae. Especially, it provides an effective method to identify the number of larval instars despite the overlap of adjacent instars.

Key words: *Curculio chinensis*; head capsule width; head capsule length; mandible width; frequency distribution; multiple peak fit; Dyar's rule

油茶象 *Curculio chinensis* Chevrolat 属鞘翅目 (Coleoptera) 象甲科 (Curculionidae), 是我国特有木本食用油料树种——油茶 *Camellia* spp. 专性蛀果害虫 (庄瑞林, 2008; 蔡守平等, 2011; 李志文等, 2014), 被国家林业局列入“全国林业危险性有害生物名单” (国家林业局防止外来林业有害生物管理办公室 2003 年发布) 之中, 在我国大多数油茶产区均有分布。油茶象生活史极不整齐 (周石涓, 1981)。全国大部分地区 2 年 1 代, 越冬成虫 4 – 6 月出土, 通过取食和产卵危害油茶果实, 卵产于种仁内, 5 月上旬开始产卵, 产卵盛期在 6 月中旬至 7 月上、中旬, 卵期 10 ~ 15 d (周石涓, 1981)。幼虫蛀食种仁, 单个果实内发育, 发育很不整齐, 6 月下旬、7 月上旬即有幼虫出果, 7 月中旬至 9 月中旬为出果盛期; 幼虫果内发育期为 16 ~ 21 d, 老熟后脱果而出, 入土作土室滞育、化蛹及羽化 (周石涓, 1981)。油茶象危害常导致大量落果 (周石涓, 1981; 华正媛等, 2012; 赵丹阳等, 2012; 舒金平等, 2013), 最严重的落果率可达 96.6% (蒋三俊, 2009), 已成为制约我国油茶产业健康发展的瓶颈 (周国英等, 2007)。

目前, 针对油茶象的防治主要是化学农药, 由于生活隐蔽, 对其生物学、生态学缺乏系统深入的研究, 因而难以制定科学合理的防控措施。昆虫分龄研究是开展生物学研究的基础 (Esperk *et al.*, 2007; Panzavolta, 2007; Cazado *et al.*, 2014)。前人室内饲养观察表明, 油茶象幼虫可分 4 龄, 并测定了各龄幼虫头壳宽极差 (周石涓, 1981)。鉴于营隐蔽生活的钻蛀性昆虫蜕皮情况难以追踪, 且室内种群龄数和头壳资料并不一定适合野外种群 (Iwantsch and Smilowitz, 1975; 李宪臣等, 1991), 有必要对油茶象野外种群开展分龄研究, 以便为生产实践服务。

确定昆虫龄数和幼虫分龄常用的方法是对骨化组织进行测量。已有数学模型用来描述测量指标随

虫龄的变化, 并用于评价测量指标区分虫龄的可靠性。戴氏法则 (Dyar's rule) 认为, 各龄幼虫大小是按几何级数增长的, 具有恒定的增长率 (Dyar, 1890), 已广泛应用于幼虫龄数的判断 (Taylor, 1931; Gaines and Campbell, 1935; Klingenberg and Zimmermann, 1992; Panzavolta, 2007; Chen and Seybold, 2013; Cazado *et al.*, 2014)。测量指标频次分布法主要是基于各龄幼虫形态指标呈正态分布的假设, 认为频次分布呈多峰分布, 每个峰均代表 1 个虫龄 (Hunt and Chapman, 2001)。当相邻虫龄测量指标不重叠时, 虫龄划分相对简单; 对于相互重叠的情况, 确定重叠区所属虫龄非常困难。国内学者多依靠自身经验进行判断, 再用 Crosby 生长法则经验公式进行评价 (柳建定等, 2008; 张海滨等, 2011; 黎保清等, 2012; 王小艺等, 2012; 杨美红等, 2012; 王智勇等, 2013); 孙艳娟等 (2009) 认为这一标准的可靠性有待商榷。国外已有研究为解决此问题提供分类法则 (Logan *et al.*, 1998; Panzavolta, 2007; Delbac *et al.*, 2010; Chen and Seybold, 2013), 但计算复杂。

本实验对油茶象开展分龄研究, 目的是探讨多峰拟合用于幼虫分龄研究的适合性, 期望为测量指标重叠区虫龄划分提供实现途径; 确定研究样地油茶象幼虫龄数, 明确各龄幼虫形态指标极差并验证戴氏法则, 为进一步开展油茶象生物学、生态学及防控研究打下基础。

1 材料与方法

1.1 研究区概况

调查的小果油茶林位于湖南省邵阳县五丰铺镇 (26°56'14.93"N, 111°28'08.32"E, 海拔 284 m)。该地位于邵阳县东南距县城约 30 km 处, 属亚热带大陆性气候, 光照充足, 四季分明, 年均气温 17.1℃,

年均降水量 1 407 mm,空气相对湿度为 80%,全年无霜期 310 d。树龄为 50 ~ 60 a,高度为 2.5 ~ 4.5 m,由于多年未进行人工抚育等管理措施,林内郁闭度较高,林下植被较少,以白茅 *Imperata cylindrica* 为主,间有加拿大蓬 *Erigeron canadensis* 及蕨类 (Pteridophyta) 植物分布。

1.2 幼虫标本的收集

选择 2 块样地收集昆虫标本。两样地相距约 700 m,中间有稻田相隔。样地 1 坡向东南,坡度 25° ~ 35°,约 3 hm²,采用平行线取样法,在试验地上、中、下坡各随机选取 7 棵样树;样地 2 地势平坦,约 0.5 hm²,随机选取 11 棵样树。两样地共 32 棵样树。

于成虫产卵高峰期(7 月初)始,随机采摘油茶果实,每次每树上、下层各 10 个,编号分装入袋。每 10 d 调查一次,直至果实采收(10 月初)止。

将所有采摘果实带回实验室,置冷藏室保存供解剖观察。逐一解剖果实和种子(每批次 3 ~ 4 d 内完成),共收集正常幼虫 1 253 头(死亡幼虫及在果实解剖中丢失或损坏幼虫不计)。所得虫卵部分置入 1.8 mL 冷冻离心管中,放入湿润棉球保湿,室温下幼虫孵化后随机选择 50 头,即为确定的初孵幼虫。另外,于油茶落果高峰期收集样树下新鲜落果,带回实验室于室温下待幼虫自动钻出,随机选择 100 头,即为确定的老熟幼虫(周石涓等,1981)。所有待测幼虫均单头置入装有 70% 酒精溶液 1.8 mL 冷冻离心管中保存。

1.3 分龄指标及测量

根据油茶象幼虫发育特点(头壳骨化程度最高)并参考前人研究结果(Panzavolta, 2007; 柳建定等, 2008; 张海滨等, 2011; 杨美红等, 2012),选用头壳宽、头壳长、上颚宽 3 个形态指标。测量工作在显微成像系统(Moticam2306 + Motic Images plus 2.0 ML)下进行(精确到 0.0001 mm),测量指标如图 1 所示。

1.4 数据统计分析

采用 Origin 9.0 和 SPSS 13.0 进行数据分析与作图。只对解剖所得 1 253 头幼虫进行频次分布研究。先将各测量指标以 0.02 mm 为组距整理成频次分布资料,然后进行多峰拟合,根据曲线单峰数量、拟合效果,并结合戴氏法则判断幼虫龄数。如相邻两峰正态曲线相交,则交点(如图 2 中 a 点或 b 点)作为虫龄分界点,误判率计算方法如下:

I 龄判为 $I-1$ 龄的误判率 = 黑色部分面积/峰

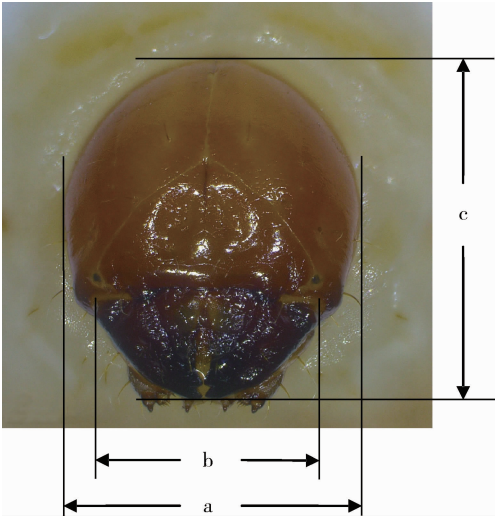


图 1 油茶象幼虫头壳测量指标

Fig. 1 Measurements of head capsule of *Curculio chinensis* larva
a: 头壳宽 Head capsule width; b: 上颚宽 Mandible width; c: 头壳长 Head capsule length.

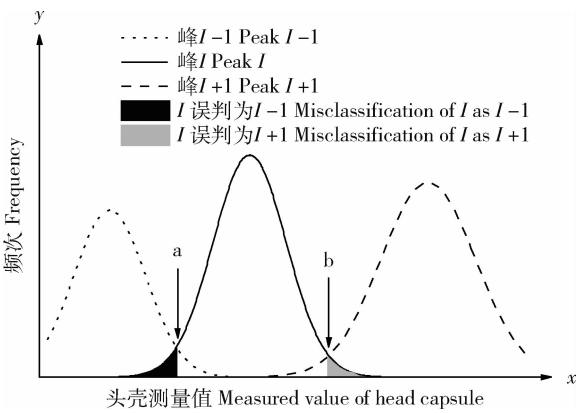


图 2 多峰拟合的交点与重叠区

Fig. 2 Points of intersection and overlapping regions of multiple peak fit

I 面积;
 I 龄判为 $I+1$ 龄的误判率 = 灰色部分面积/峰 I 面积。

2 结果

2.1 油茶象幼虫龄数

油茶象幼虫头壳宽 0.298 ~ 2.199 mm,头壳长 0.307 ~ 2.525 mm,上颚宽 0.168 ~ 1.576 mm,频次分布均呈多峰分布(图 3 ~ 5)。多峰拟合显示,各测量指标均具 5 个明显的正态峰($P < 0.01$),各峰正态曲线参数见表 1。根据频次分布每个正态峰对应

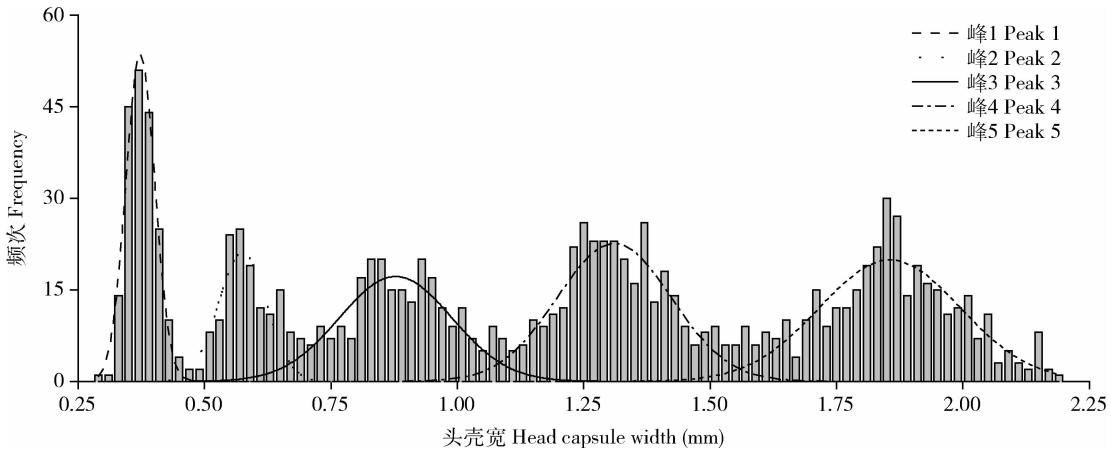


图 3 油茶象幼虫头壳宽频次分布
Fig. 3 Frequency distributions of the head capsule width of *Curculio chinensis* larvae

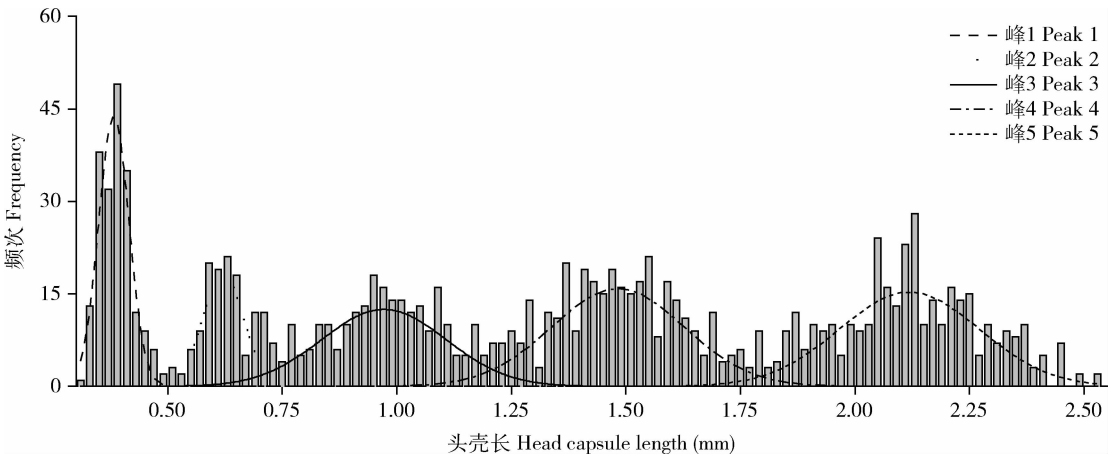


图 4 油茶象幼虫头壳长频次分布
Fig. 4 Frequency distributions of the head capsule length of *Curculio chinensis* larvae

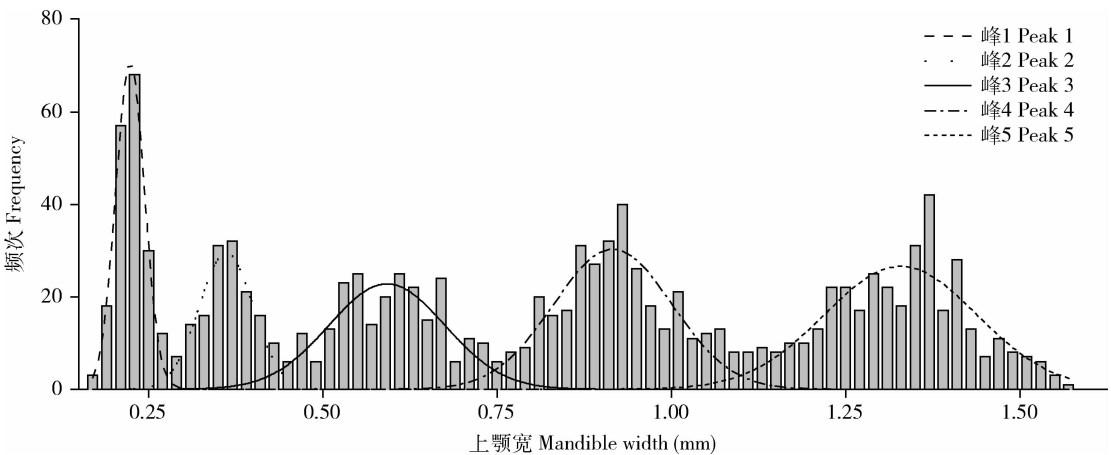


图 5 油茶象幼虫上颚宽频次分布
Fig. 5 Frequency distributions of the mandible width of *Curculio chinensis* larvae

表 1 油茶象各龄幼虫头壳宽、头壳长及上颚宽频次分布多峰拟合

Table 1 Multiple peak fit of frequency distribution of the head capsule width, head capsule length and mandible width for all instars of *Curculio chinensis* larvae

幼虫虫龄 Larval instar	多峰拟合 Multiple peak fit						
	拟合效果 Fitting effect			参数 Parameter			
	Adj. R^2	F	P	y_0	x_c	W	A
头壳宽 Head capsule width	0.848	115.368	0.000				
1 龄 1st instar				0.000	0.373	0.058	3.858
2 龄 2nd instar				0.000	0.575	0.095	2.517
3 龄 3rd instar				0.000	0.878	0.222	4.774
4 龄 4th instar				0.000	1.311	0.226	6.397
5 龄 5th instar				0.000	1.856	0.279	6.933
头壳长 Head capsule length	0.697	64.566	0.000				
1 龄 1st instar				0.000	0.382	0.067	3.654
2 龄 2nd instar				0.000	0.621	0.089	2.047
3 龄 3rd instar				0.000	0.972	0.272	4.247
4 龄 4th instar				0.000	1.483	0.291	5.755
5 龄 5th instar				0.000	2.118	0.305	5.842
上颚宽 Mandible width	0.815	73.260	0.000				
1 龄 1st instar				0.000	0.224	0.041	3.663
2 龄 2nd instar				0.000	0.361	0.077	2.867
3 龄 3rd instar				0.000	0.592	0.166	4.750
4 龄 4th instar				0.000	0.916	0.169	6.430
5 龄 5th instar				0.000	1.329	0.219	7.278

多峰拟合 Gauss 函数 Gauss function of multiple peak fit: $y = y_0 + \frac{A}{W \sqrt{\pi/2}} e^{-2\frac{(x-x_c)^2}{W^2}}$.

1 个虫龄的原则,可将油茶象幼虫分为 5 龄。以正态曲线交点作为分界点划分虫龄,其平均值、极差、增长率及误判率见表 2。比较峰 1 与初孵幼虫、峰 5 与老熟幼虫头壳宽、头壳长及上颚宽平均值与极差,两者基本吻合,说明峰 1 对应虫龄为初孵幼虫(属 1 龄),峰 5 对应虫龄为老熟幼虫(属 5 龄)。各龄幼虫增长率基本恒定,头壳宽、头壳长及上颚宽增长率依次为 1.41~1.54,1.43~1.61 和 1.44~1.64。各测量指标平均值自然对数与虫龄线性相关极为显著($P < 0.01$)(图 6),完美的线性关系表明没有虫龄错漏,各龄幼虫测量指标呈间断性几何级数增长,符合戴氏法则,进一步证实油茶象幼虫分为 5 龄是合理的。

2.2 油茶象幼虫分龄及分龄指标

图 3~5 表明,头壳宽、头壳长及上颚宽频次分布尽管呈明显的 5 个峰,但各峰之间并无间断,说明相邻虫龄测量指标存在重叠现象,这给幼虫分龄带来困难,无法确定重叠区(即峰谷)所属虫龄。本文通过多峰拟合,以正态曲线交点作为分界点划分虫龄。表 2 显示,3 个测量指标中,均以 3 龄幼虫误判率(误判为 2 龄或 4 龄)最高,2 龄及 4 龄次之,1 龄和 5 龄最低,说明 3 龄幼虫最易引起误判。除 3 龄幼虫误判率稍 >5% 外,其余虫龄误判率均 <5%,说明头壳宽、头壳长和上颚宽 3 个形

态指标均可作为油茶象幼虫分龄的可靠指标。表 2 还表明,误判率最大值以头壳宽最小(6.04%),上颚宽居中(6.51%),头壳长最大(7.03%),说明 3 个可靠分龄指标中,头壳宽最佳,上颚宽次之,头壳长稍差。根据测量指标极差(表 2)可确定幼虫虫龄。

3 结论与讨论

3.1 油茶象幼虫龄数的确定

本研究表明,油茶象分为 5 龄,不同于周石涓(1981)室内蜕皮观察只有 4 龄(其各龄幼虫头壳宽极差分别为 0.25~0.50,0.75~1.00,1.25~1.95 和 1.90~2.00 mm)。比较发现,本研究中相邻虫龄头壳宽资料相互重叠(图 3~5),而后者则相互间断。本研究中 2 龄幼虫头壳宽极差(0.455~0.670 mm)基本位于后者 1 龄与 2 龄幼虫头壳宽间隔区,未被后者记录认知。研究结果不同,可能与油茶象活动隐蔽及样本大小有关。

频次分布法研究昆虫分龄要求样本数量足够大。当样本数量不足时,有可能导致虫龄错漏,从而使幼虫龄数减少。本研究中,样本数量 1 253 头,多峰拟合显示,各测量指标频次分布均呈多峰曲线分

表 2 油茶象各龄幼虫头壳宽、头壳长及上颚宽平均数、极差、增长率及误判率
Table 2 Means, range, growth ratio, and misclassification probability of the head capsule width, head capsule length and mandible width for all instars of *Curculio chinensis* larvae

测量指标 Measurements	幼虫虫龄 Larval instar	样本量 Sample size	平均值 ± SD (mm) Mean ± SD	极差 (mm) Range	增长率 Growth ratio	误判率 (%) Misclassification probability		
						I as I - 1	I as I + 1	合计 Total
头壳宽 Head capsule width	初孵幼虫 Newly hatched larva ^a	50	0.378 ± 0.026	0.306 - 0.428				
	1 龄 1st instar	194	0.376 ± 0.028	0.298 - 0.455		-	0.21	0.21
	2 龄 2nd instar	134	0.580 ± 0.046	0.455 - 0.670	1.54	0.53	2.25	2.78
	3 龄 3rd instar	240	0.881 ± 0.101	0.670 - 1.085	1.52	2.93	3.11	6.04
	4 龄 4th instar	327	1.315 ± 0.109	1.085 - 1.560	1.49	2.22	1.36	3.58
	5 龄 5th instar	358	1.852 ± 0.140	1.560 - 2.199	1.41	1.65	-	1.65
头壳长 Head capsule length	老熟幼虫 Mature larva ^b	100	1.861 ± 0.121	1.597 - 2.160				
	初孵幼虫 Newly hatched larva	50	0.390 ± 0.030	0.307 - 0.443				
	1 龄 1st instar	196	0.387 ± 0.034	0.307 - 0.487		-	0.08	0.08
	2 龄 2nd instar	125	0.622 ± 0.049	0.487 - 0.715	1.61	0.12	1.56	1.68
	3 龄 3rd instar	249	0.971 ± 0.127	0.715 - 1.206	1.56	2.92	4.11	7.03
	4 龄 4th instar	335	1.491 ± 0.142	1.206 - 1.795	1.54	2.83	1.54	4.37
上颚宽 Mandible width	5 龄 5th instar	348	2.125 ± 0.159	1.795 - 2.525	1.43	1.69	-	1.69
	老熟幼虫 Mature larva	100	2.111 ± 0.158	1.803 - 2.492				
	初孵幼虫 Newly hatched larva	50	0.230 ± 0.021	0.185 - 0.273				
	1 龄 1st instar	186	0.224 ± 0.021	0.168 - 0.277		-	0.45	0.45
	2 龄 2nd instar	149	0.362 ± 0.039	0.277 - 0.440	1.62	1.42	2.07	3.49
	3 龄 3rd instar	233	0.594 ± 0.074	0.440 - 0.746	1.64	3.29	3.22	6.51
	4 龄 4th instar	327	0.920 ± 0.082	0.746 - 1.100	1.55	2.15	1.47	3.62
	5 龄 5th instar	358	1.324 ± 0.102	1.100 - 1.576	1.44	1.78	-	1.78
	老熟幼虫 Mature larva	100	1.333 ± 0.086	1.111 - 1.521				

^a 刚从油茶象卵中孵化而出的幼虫 Larvae newly hatched from eggs of *C. chinensis*; ^b 刚从寄主植物小果油茶落果中钻出的幼虫 Larvae newly exited from the fallen fruits of the host plant *Camellia meiocarpa*.

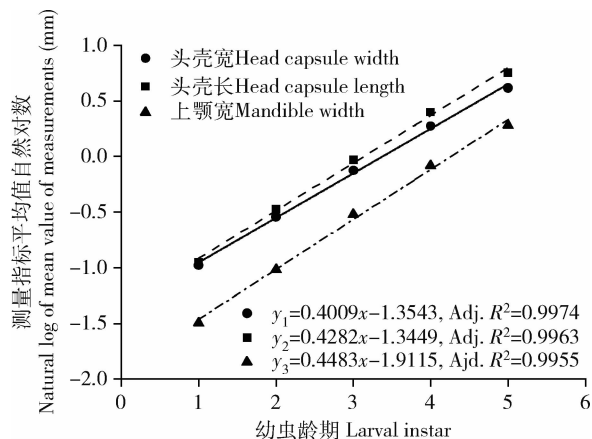


图6 油茶象幼虫头壳宽、头壳长及上颚宽平均值的自然对数与虫龄的回归关系

Fig. 6 Regression relationship between the natural logarithm of the means of the head capsule width, head capsule length and mandible width of all instars of *Curculio chinensis* larvae and the instar number

布(图3~5, $P < 0.01$),相邻两峰分布连续,没有间断,且峰1、峰5分别与初孵幼虫和老熟幼虫头壳资料能较好吻合,说明没有虫龄错漏。根据频次分布每个正态峰代表一个虫龄(Hunt and Chapman, 2001)的原则,可将油茶象幼虫分为5龄,戴氏法则进一步验证了其合理性(图6)。测量指标频次分布法在其他钻蛀性昆虫或野外种群分龄研究中,均取得了可靠的结果(Logan *et al.*, 1998; Panzavolta, 2007; Delbac *et al.*, 2010; Chen and Seybold, 2013; Cazado *et al.*, 2014)。

3.2 最佳分龄指标

昆虫骨化部分生长是不连续的,伴随着周期性的蜕皮而跳跃式地增长(Dyar, 1890),因此骨化部位是判断虫龄非常有用的标准(Daly, 1985),在很多昆虫分龄研究中得到应用,其中以头壳宽应用最为广泛(Panzavolta, 2007)。但并不是所有骨化组织均有相同的效力。杨美红等(2012)对榆木蠹蛾 *Holcocerus vicari* 研究表明,头壳宽是最佳分龄指标,上颚长稍逊于上颚宽。张海滨等(2011)对星天牛 *Anoplophora chinensis* 研究也表明,上颚长分龄效果不如上颚宽和额宽,可能原因是上颚弯曲程度存在较大差异,导致测量值不能反映上颚真正长度。本实验中,由于油茶象上颚张合位置不同,上颚真实长度难以测量(对头壳长也有一定影响,但不显著),因此测量指标不包括上颚长。在所选的3个测量指标中,头壳宽、上颚宽优于头壳长,而 Panzavolta

(2007)对 *Pissodes castaneus* 的分龄研究表明,头壳长误判率低于头壳宽,认为二者均能有效判断虫龄。对油茶象头壳测量表明,测量视角显著影响头壳长,但对头壳宽及上颚宽影响较少,实验结果基本体现了这一问题。为保证测量准确,统一测量标准至关重要。

3.3 果实质量对油茶象幼虫分龄的影响

本研究中,相邻幼虫测量指标存在重叠现象。对象虫科其他昆虫的研究,也有类似的情况(Panzavolta, 2007; Cazado *et al.*, 2014)。一般认为,这与样本大小密切相关(McClellan and Logan, 1994; Delbac *et al.*, 2010),但更为重要的是,可能反映了个体间本身的变异程度。研究表明,昆虫发育、大小(如头壳宽等)受多种因素影响,如温湿度、种内种间竞争、食物条件等(Howe, 1956; Leonard, 1968; Hunter and Willmer, 1989; Wise and Weinberg 2002; Shintani *et al.*, 2003; Hanks *et al.*, 2005; Goguen and Moreau, 2013)。对油茶象而言,由于幼虫在单个寄主果实内发育,因此寄主果实可利用食物资源及品质成为制约幼虫发育的重要因子。小果实育出幼虫体质量显著降低(李志文等, 2014),不仅如此,果实大小不同,其保温保湿能力亦有差异,进一步影响油茶象幼虫发育,最终导致相邻虫龄测量指标存在较大程度的重叠,客观上引起误判率增大。

3.4 多峰拟合在昆虫分龄研究中的应用

用频次分布法进行昆虫分龄研究,当相邻虫龄测量指标相互重叠时,准确判断重叠区所属虫龄及其重叠程度非常困难。国内学者多依靠自身经验进行判断,再用 Crosby 生长法则经验公式进行评价。国外则根据测量指标呈正态分布的假设提出了最佳分割原则,已有计算机程序(Hcap)用于此类研究(Logan *et al.* 1998)。本文根据其基本原理,采用 Origin 9.0 程序中的多峰拟合工具,可以较为方便地实现上述过程。进行多峰拟合时,其内置正态曲线函数为 $y = y_0 + \frac{A}{W \sqrt{\pi/2}} e^{-\frac{(x-x_c)^2}{W^2}}$ (y 为测量指标频次, x 为测量值, y_0 , x_c , W 和 A 为方程参数),须令 $y_0 = 0$ 再进行迭代演算方可得到合乎要求的图像。研究结果表明:油茶象具有5个虫龄,并给出了幼虫分龄标准;明确了相邻虫龄的重叠尺度,并分析了其可能的原因,这对于建立种群生命表,进行有关生物学、生态学方面的研究以及理解油茶象的行为习性,提出合理的管理对策非常重要。多峰拟合也可为其

他钻蛀性昆虫或野外种群的虫龄划分提供新的切实可行的途径。

致谢 英文摘要承荷兰皇家自然历史博物馆 C. van Achterberg 博士修改,特此致谢。

参考文献 (References)

- Cai SP, He XY, Li ZZ, Xiong Y, Huang JS, Zhou SY, 2011. Study on damage of *Curculio chinensis* on *Camellia oleifera* fruit. *Journal of Fujian Forestry Science and Technology*, 38(2): 14–16. [蔡守平, 何学友, 李志真, 熊瑜, 黄金水, 周世炎, 2011. 油茶象危害油茶果实的初步研究. 福建林业科技, 38(2): 14–16]
- Cazado LE, van Nieuwenhove GA, O'Brien CW, Gastaminza GA, Murúa MG, 2014. Determination of number of instars of *Rhyssomatus subtilis* (Coleoptera: Curculionidae) based on head capsule widths. *Florida Entomologist*, 97(2): 639–643.
- Chen Y, Seybold SJ, 2013. Application of a frequency distribution method for determining instars of the beet armyworm (Lepidoptera: Noctuidae) from widths of cast head capsules. *Journal of Economic Entomology*, 106(2): 800–806.
- Daly HV, 1985. Insect morphometrics. *Annual Review of Entomology*, 30(1): 415–438.
- Delbac L, Lecharpentier P, Thiery D, 2010. Larval instars determination for the European grapevine moth (Lepidoptera: Tortricidae) based on the frequency distribution of head-capsule widths. *Crop Protection*, 29(6): 623–630.
- Dyar HG, 1890. The number of molts in lepidopterous larvae. *Psyche*, 5: 420–422.
- Esperk T, Tammaru T, Nylin S, 2007. Intraspecific variability in number of larval instars in insects. *Journal of Economic Entomology*, 100(3): 627–645.
- Gaines JC, Campbell FL, 1935. Dyar's rule as related to the number of instars of the corn ear worm, *Heliothis obsoleta* (Fab.), collected in the field. *Annals of the Entomological Society of America*, 28(4): 445–461.
- Goguen J, Moreau G, 2013. Factors affecting head capsule development in field populations of *Altica sylvia* (Coleoptera: Chrysomelidae). *Canadian Entomologist*, 145(1): 40–47.
- Hanks LM, Paine TD, Millar JG, 2005. Influence of the larval environment on performance and adult body size of the wood-boring beetle *Phoracantha semipunctata*. *Entomologia Experimentalis et Applicata*, 114(1): 25–34.
- Howe RW, 1956. The biology of the two common storage species of *Oryzaephilus* (Coleoptera, Cucujidae). *Annals of Applied Biology*, 44(2): 341–355.
- Hua ZY, Wang JT, Liu J, Wang HJ, Shu JP, Xu TS, 2012. Insect pests of *Camellia oleifera* and their natural enemies in Quzhou, China. *Journal of Zhejiang Agriculture and Forestry University*, 29(2): 232–243. [华正媛, 王井田, 刘剑, 王浩杰, 舒金平, 徐天森, 2012. 衢州市油茶害虫及天敌种类调查. 浙江农林大学学报, 29(2): 232–243]
- Hunt G, Chapman RE, 2001. Evaluating hypotheses of instar-grouping in arthropods: a maximum likelihood approach. *Paleobiology*, 27(3): 466–484.
- Hunter MD, Willmer PG, 1989. The potential for interspecific competition between two abundant defoliators on oak: leaf damage and habitat quality. *Ecological Entomology*, 14(3): 267–277.
- Iwantsch GF, Smilowitz Z, 1975. Relationships between the parasitoid *Hyposoter exiguae* and the cabbage looper, *Trichoplusia ni*: effects on head capsule width, live and dry weights, and hemolymph specific gravity of hosts at different ages. *Canadian Entomologist*, 107(9): 927–934.
- Jiang SJ, 2009. Control of the camellia weevil. *Special Economic Animal and Plant*, 12(8): 54–54. [蒋三俊, 2009. 油茶象鼻虫的防治. 特种经济动植物, 12(8): 54–54]
- Klingenberg CP, Zimmermann M, 1992. Dyar's rule and multivariate allometric growth in nine species of waterstriders (Heteroptera: Gerridae). *Journal of Zoology*, 227(3): 453–464.
- Leonard DE, 1968. Effects of density of larvae on the biology of the gypsy moth (*Porthetria dispar*). *Entomologia Experimentalis et Applicata*, 11(3): 291–304.
- Li BQ, Ji BZ, Liu SW, Wang GX, Zhang K, Wu H, 2012. Study on larvae instar number and division criterion of *Apriona germari*. *China Forestry Science and Technology*, 26(3): 38–41. [黎保清, 嵇保中, 刘曙雯, 王国兴, 张凯, 吴华, 2012. 桑天牛幼虫龄数与划分特征研究. 林业科技开发, 26(3): 38–41]
- Li XC, Feng JM, Liu HX, 1991. Test of carpenterworm moth larvae fed with semi-synthetic diet. *Journal of Shandong Forestry Science and Technology*, (3): 56–59. [李宪臣, 冯健民, 刘焕秀, 1991. 人工半合成饲料饲养木蠹蛾幼虫试验. 山东林业科技, (3): 56–59]
- Li ZW, He LH, Ma L, Xia J, Zeng AP, 2014. Influence of fruit size of *Camellia meiocarpa* on growth of oil tea weevil, *Curculio chinensis* (Coleoptera: Curculionidae). *Chinese Journal of Applied Ecology*, 25(12): 3580–3586. [李志文, 何立红, 马玲, 夏姣, 曾爱平, 2014. 果实大小对油茶象幼虫生长的影响. 应用生态学报, 25(12): 3580–3586]
- Liu JD, Li BW, Wang JY, Zhao BA, Shu JP, 2008. Primary study on methods to determine instars of *Monochamus alternatus* larva. *Journal of Zhejiang Forestry Science and Technology*, 28(4): 84–86. [柳建定, 李百万, 王菊英, 赵宝安, 舒金平, 2008. 松褐天牛龄级划分方法初探. 浙江林业科技, 28(4): 84–86]
- Logan JA, Bentz BJ, Vandygriff JC, Turner DL, 1998. General program for determining instar distributions from headcapsule widths: example analysis of mountain pine beetle (Coleoptera: Scolytidae) data. *Environmental Entomology*, 27(3): 555–563.
- McClellan QC, Logan JA, 1994. Instar determination for the gypsy moth (Lepidoptera: Lymantriidae) based on the frequency distribution of head capsule widths. *Environmental Entomology*, 23(2): 248–253.
- Panzavolta T, 2007. Instar determination for *Pissodes castaneus* (Coleoptera: Curculionidae) using head capsule widths and lengths. *Environmental Entomology*, 36(5): 1054–1058.
- Shintani Y, Munyiri FN, Ishikawa Y, 2003. Change in significance of feeding during larval development in the yellow-spotted longicorn

beetle, *Psacotha hilaris*. *Journal of Insect Physiology*, 49(10): 975–981.

Shu JP, Teng Y, Liu J, Zhang YB, Wang HJ, 2013. Preliminary analysis on the causes of pre-harvest fruit drop in *Camellia oleifera*. *China Plant Protection*, 33(1): 9–14. [舒金平, 滕莹, 刘剑, 张亚波, 王浩杰, 2013. 油茶采前落果原因初步分析. 中国植保导刊, 33(1): 9–14]

Sun YJ, Wei JY, Yang ZD, Li M, Wei YL, Wei HH, 2009. Classification on larvae instars of *Buzura suppressaria*. *Chinese Bulletin of Entomology*, 46(6): 892–895. [孙艳娟, 韦金英, 杨振德, 李明, 韦泳丽, 韦海花, 2009. 油桐尺蠖幼虫龄期的划分. 昆虫知识, 46(6): 892–895]

Taylor RL, 1931. On “Dyar’s rule” and its application to sawfly larvae. *Annals of the Entomological Society of America*, 24(3): 451–466.

Wang XY, Yang ZQ, Tang YL, Jiang J, Yang YL, Gao C, 2012. Determination of larval instar number and duration in the oak longhorn beetle, *Massicus raddei* (Coleoptera: Cerabycidae). *Acta Entomologica Sinica*, 55(5): 575–584. [王小艺, 杨忠岐, 唐艳龙, 姜静, 杨远亮, 高纯, 2012. 栗山天牛幼虫龄数和龄期的测定. 昆虫学报, 55(5): 575–584]

Wang ZY, Zhang YL, Yang ZQ, Wang XY, 2013. Determination of larval instars of *Agrilus mali* Matsumura (Coleoptera: Buprestidae). *Forest Research*, 26(6): 786–789. [王智勇, 张彦龙, 杨忠岐, 王小艺, 2013. 苹小吉丁(鞘翅目: 吉丁甲科)幼虫龄数的测定. 林业科学研究, 26(6): 786–789]

Wise MJ, Weinberg AM, 2002. Prior flea beetle herbivory affects oviposition preference and larval performance of a potato beetle on their shared host plant. *Ecological Entomology*, 27(1): 115–122.

Yang MH, Zhang JT, Zong SX, Luo YQ, Niu HL, Zhang B, 2012. Determination of the larval instar number of the carpenter moth *Holcocerus vicarious* (Lepidoptera: Cossidae). *Acta Entomologica Sinica*, 55(6): 710–718. [杨美红, 张金桐, 宗世祥, 骆有庆, 牛辉林, 张彪, 2012. 榆木蠹蛾幼虫龄数的确定. 昆虫学报, 55(6): 710–718]

Zhang HB, Wang JW, Zhu XF, Chen XX, 2011. Determination of larval instars of citrus long-horned beetle, *Anoplophora chinensis* (Coleoptera: Cerambycidae). *Chinese Journal of Applied Entomology*, 48(3): 688–694. [张海滨, 王建伟, 朱小峰, 陈学新, 2011. 星天牛幼虫龄期的划分. 应用昆虫学报, 48(3): 688–694]

Zhao DY, Qin CS, Jie RZ, Xu JZ, Yang H, 2012. Investigation on diseases and pests species of *Camellia oleifera* and their occurrence dynamics in Guangdong. *Journal of Anhui Agricultural Sciences*, 40(29): 14267–14270. [赵丹阳, 秦长生, 揭育泽, 徐金柱, 杨华, 2012. 广东省油茶病虫害种类及发生动态调查. 安徽农业科学, 40(29): 14267–14270]

Zhou GY, Song GT, Li H, 2007. Present situation and countermeasures to control *Camellia oliefera* pest and disease. *Journal of Central South University of Forestry & Technology*, 27(6): 179–182. [周国英, 宋光桃, 李河, 2007. 油茶病虫害防治现状及应对措施. 中南林业科技大学学报, 27(6): 179–182]

Zhou SJ, 1981. Biology and control of camellia weevil *Curculio chinensis* Chevrolat. *Acta Entomologica Sinica*, 24(1): 48–52. [周石涓, 1981. 油茶象的生物学及其防治. 昆虫学报, 24(1): 48–52]

Zhuang RL, 2008. Oil-tea *Camellia* of China. 2nd ed. China Forestry Press, Beijing. 366 pp. [庄瑞林, 2008. 中国油茶(第2版). 北京: 中国林业出版社. 366 页]

(责任编辑: 袁德成)